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# COUNTS OF CALIFORNIA SEA LION (*ZALOPHUS CALIFORNIANUS*) PUPS FROM AERIAL COLOR PHOTOGRAPHS AND FROM THE GROUND: A COMPARISON OF TWO METHODS

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## ABSTRACT

Pups on San Nicolas Island were counted by two methods; counts by observers on the ground were compared to counts from aerial photographs taken with a 126-mm-format camera with image motion compensation. No difference was detected between photographic counts and ground counts ($P$ = 0.367) when ground counters had unobstructed views. However, ground counts were significantly lower when areas with obstructed views were included in the analysis ($P$ < 0.001). For areas with unobstructed viewing conditions, no difference was detected between counts by the two methods for rock substrates ($P$ = 0.140), sand substrates ($P$ = 0.468), or mixed rock-and-sand substrates ($P$ = 0.968). No differences were found among three replicate aerial photographic censuses ($P$ = 0.432), but a significant difference was found between two replicate ground censuses ($P$ = 0.037). Total counts obtained from the aerial photographs were more precise (CV = 0.042) than counts obtained on the ground (CV = 0.078). Less variability in counts was found between photographic counters than for ground counters.

Key words: California sea lion, *Zalophus californianus,* pups, San Nicolas Island, vertical aerial photographic counts, 126-mm-format photography, ground counts, replicate surveys.

Counts of California sea lion (*Zalophus californianus*) pups are used as indices of population size and trends (DeMaster *et al.* 1982, Barlow *et al.* 1995). Pups have been counted by observers on the ground or offshore in small boats and from aerial photographs (Braham 1974, Le Bouef *et al.* 1983, DeMaster *et al.* 1982, Beeson and Hanan 1996, Zavala-Gonzalez and Mellink 1997). Ground counting, the most common method, is conducted from atop bluffs, from behind natural structures (*i.e.,* rocks, logs, vegetation) or artificial blinds, or by walking among or near sea lions. Counts from boats are usually made from within 30 to

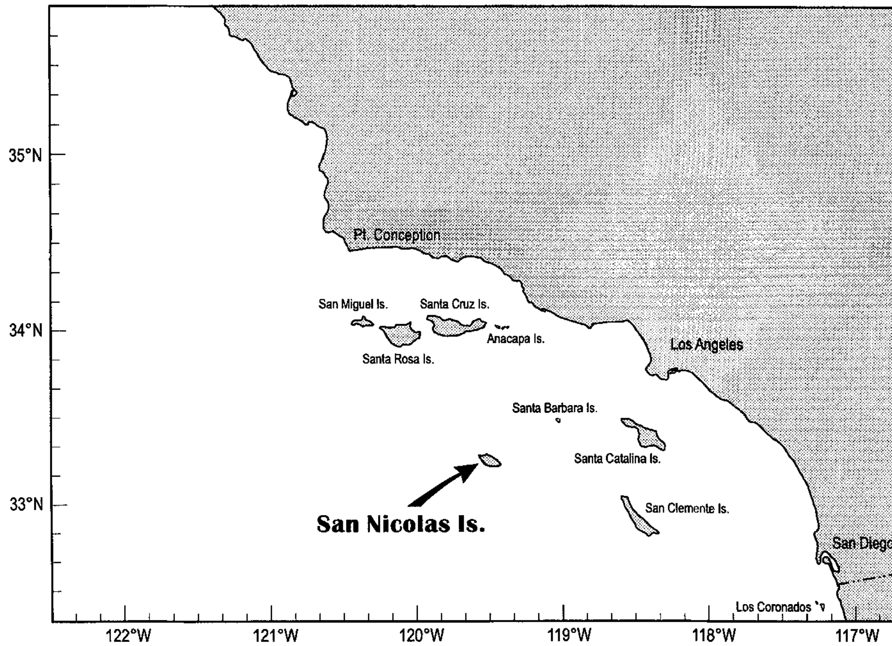


*Figure 1.* Map of Southern California Bight showing location of San Nicolas Island.

50 m of the shoreline. Dense aggregations of sea lions are difficult to count from the ground or from a boat, and counts are complicated by movements of individual sea lions, visual obstructions, human and avian disturbance (resulting in additional movement of sea lions), or boat movement. The problem of sea lion movement becomes inconsequential with aerial photographs, but camera systems used in the past did not provide sufficient resolution to distinguish individual pups in dense aggregations, especially on rocky substrates.

Various photographic films and camera systems, including color or black-and-white 35 mm, 70 mm, and 228 mm, have been used to photograph and enumerate California sea lions (Bartholomew and Boolootian 1960, Odell 1971, Braham 1974, Beeson and Hanan 1996). The Southwest Fisheries Science Center (SWFSC) uses 126-mm-format cameras equipped with image motion compensation (IMC) that eliminates image smear. This system, which has been used to census northern elephant seals (*Mirounga angustirostris*) and Steller sea lions (*Eumetopias jubatus*) (Lowry *et al.* 1996, Westlake *et al.* 1997), produces high-resolution photographs suitable for enumerating California sea lion pups in dense aggregations and on rocky substrates. Counts of pups made by observers on the ground were compared to counts obtained from 126-mm-format color-transparency photographs taken at San Nicolas Island, California (Fig. 1) to evaluate the 126-mm-format IMC camera system. I compared precision and accuracy of ground and aerial counts, evaluated the effects of different substrate types on these counts, and examined counts by experienced and inexperienced observers.

## METHODS

*Photography equipment*—Photographs were taken with a Chicago Aerial Industries, Inc. model KA-45A or KA-76 camera equipped with IMC and a 152-mm-focal-length lens. The distance between the lens and the film support base was adjusted to keep the fixed lens in focus at an altitude as low as 129 m. The camera was mounted vertically in a twin-engine Partenavia PN68C or PN68-observer model aircraft. The aircraft were flown at a ground speed between 90 and 110 kn and at an altitude between 183 and 259 m (typically 244 m). Kodak Aerochrome MS Film 2448, a very fine-grained, medium-speed, color transparency film was used. The film was exposed for normal contrast on sand substrates and overexposed between one-half and one f-stop for rocky substrates. The camera, set at an aperture of f/5.6 and a shutter speed between 1/400 and 1/1,500 sec (depending on light condition), was operated at a cycle rate that achieved 67% overlap between adjacent frames.

*Censuses*—Ground censuses and aerial photographic censuses were conducted at San Nicolas Island during late breeding season after nearly all pups had been born (see Morales-Vela and Aguayo-Lobo 1992) and before they ventured into the open ocean. Ground censuses were conducted on 16–17 July 1992, 16–18 July and 23–26 July 1993, and 12–13 July 1994. In 1992 and 1994 the rookery was divided among three ground observers (yielding one complete total count for each year). In 1993 the rookery was censused twice, each time by a team of two different ground observers who each counted the entire rookery (yielding four total independent counts). Aerial censuses, some of which occurred during ground censuses, were conducted on 18 and 23 July 1992; 11, 15, and 17 July 1993; 14 and 16 July 1994; 21 and 22 July 1995; and 21 and 22 July 1996. More than one aerial census was made each year to evaluate variability of aerial photographic censuses.

The sea lions were unevenly distributed along the southern and western shoreline of San Nicolas Island. The shoreline was divided into 56 unequally sized areas. These areas, some of which contained no sea lions or no sea lion pups, were categorized by type of substrate (sand, rock, or a mixture of both) and by the quality of the ground observer's view for each area (obstructed or unobstructed). The areas designated as obstructed and unobstructed and categorized by substrate type were the same every year, but number of pups in each area differed from year to year due to annual differences in pup production. Photocopies of high-altitude photographs, picturing area boundaries, were used by ground observers and photographic counters to insure that counts were comparable in coverage for each area.

*Ground counts*—The sea lions were not disturbed while being counted during ground censuses. Live pups were tallied with mechanical hand-counters as animals were viewed by naked eye or through binoculars. Although each ground observer could make several counts of the same group of pups, only the count judged by the observer to be best was recorded.

*Photographic counts*—Pups were counted through a 7–70× zoom binocular microscope as the color transparency photograph was illuminated on a light table. Non-decomposed dead pups were not distinguishable from live pups and were included in the counts. Carcasses of decomposed pups were tallied but were not included in the counts (the total count for the island would be augmented by 0.2%–1.6% if carcasses were included). Pups were marked on a clear acetate plastic overlay with a 0.1-mm-point pen as each was counted. Marks on the acetate were compared and verified with overlapping photographs (allowing the counter to view each pup from two additional angles to verify the marked pup counted). After completing the confirmation procedure, the acetate was placed on another photograph at the exact position of the coastline where the count ended previously and the count resumed on the uncounted portion. Pups were counted in this manner for each aerial photographic census until the entire coastline was examined. High-altitude (1,400 m) photographs and my knowledge of geographical features on the ground were used to orient the low-altitude photographs. I made one complete count from each photographic census except the 1993 censuses, which were counted twice.

*Analysis of census data*—The blocking factor "area" was used in an incomplete block design ANOVA or in a randomized block design ANOVA to analyze counts collected from each area during ground and aerial photographic censuses. The Tukey HSD pairwise mean comparison *post hoc* test was made when significant interaction effects were detected. The counts were 0.3-power-transformed, because their distribution was skewed toward zero. For these analyses, the following assumptions were made:

(1) Pups stayed in the same area and did not go to sea.
(2) Pup mortality was insignificant between censuses.
(3) All ground and photographic counters interpreted the boundaries between adjoining areas accurately.

To detect the direction in which counts differed, ground counts were paired with photographic counts for each area and year. Linear regression analysis was then used to detect the extent and direction that paired-counts deviated from symmetry (*i.e.*, slope = 1). A significance level of 5% ($\alpha$ = 0.05) was used for all analyses.

*Census-method comparison*—Ground counts and photographic counts of each area from censuses conducted in 1992–1994 were used to evaluate differences between counting methods for the following: (1) all counts, (2) counts in which the ground observer had an unobstructed view or an obstructed view, and (3) counts on three substrate types (rock, sand, and mixed rock-and-sand). An incomplete block design ANOVA was used to test the null hypothesis that there was no significant difference between ground counts and photographic counts.

*Replicate censuses*—The 1993 data, comprising three aerial photographic censuses and two ground censuses, were analyzed separately for each method. Randomized block design ANOVA of ground-counts tested for (1) differences between the two ground censuses and (2) differences between the observers conducting each ground census (observers were nested within each census).

Incomplete block design ANOVA of aerial photographic counts was used to test for (1) differences between photographic censuses, (2) differences between repeated counts within each census, and (3) interaction effects between counts and censuses.

The 1992–1996 photographic counts were used to test for differences between photographic censuses (nested within year) in a randomized block design ANOVA. This analysis was used to evaluate differences between photographic censuses conducted within a few days of each other when several years of data were included in the analysis.

Counts of pups from all areas collected during replicate censuses in 1993 were summed for each ground observer and photographic counter to produce several total counts for each census (see Appendix A). The coefficients of variation (CV) for small sample sizes (Sokal and Rohlf 1995) from these totals were then used to compare precision of total counts obtained from censuses by each method.

*Replicate counts*—Replicate independent counts by observers on the ground were compared with replicate independent counts for the same area by different counters from aerial photographs taken while the ground count was in progress. These comparisons eliminated the effect caused by pup mortality on counts separated by one or more days and provided data for determining precision and accuracy of counts obtained by each method. Two areas with unobstructed views were chosen.

Area 44 had a sand substrate and two distinct groups of sea lions (groups A and B). Group A was a small breeding/pupping group (<100 pups), and group B was a medium-sized breeding group (100–500 pups). Area 44 was photographed once on 14 July 1994, and pups from groups A and B were counted on the ground (at the same time) by three experienced observers and from photographs by two experienced (ground) counters. Ground observers and photographic counters made three independent counts each. Photographic counters made their counts on separate days, to reduce the chance of them remembering their previous counts.

Area 50 had approximately 80% rock substrate and 20% sand substrate and a large breeding group (>500 pups). Area 50 was photographed twice within 10 min on 15 July 1995, during the period when pups were counted on the ground by one experienced ground observer and eight inexperienced ground observers. Eight ground observers made five (consecutive) independent counts each, and one made four. Pups were counted from photographs by three experienced and three inexperienced counters. Photographic counters counted pups from one of two overflights. Five counts from each overflight by an experienced counter showed no difference between pup counts from the two overflights (df $= 4$, $F = 2.491$, $P = 0.199$). Photographic counts were separated by no less than an hour and by up to one or more days.

The CVs for small sample sizes were computed from replicate counts of pups to compare precision of ground counts with precision of photographic counts. CVs were computed for counts made at Areas 44 and 50 and for ground counts obtained in July 1993 at six areas for control. Control CVs are examples of precision levels achieved by experienced ground observers and were used to gauge CVs derived from counts conducted at Areas 44 and 50. Control CVs were computed from counts by two teams of two ground observers (each observer made two to five counts). A CV value was calculated for each individual counter and for the aggregate of counts from two or more counters. Replicate counts and CVs were analyzed with either the Kruskal-Wallis test or the Scheirrer-Ray-Hare extension of the Kruskal-Wallis test (Sokal and Rohlf 1995) when counts and CV values exhibited heteroscedasticity and skewed distributions.

Accuracy of each method was ascertained by comparing CVs of individual counts with CVs of grouped counts and by examining counts by two or more counters. Agreement between precision of individual counts and precision of grouped counts, and agreement between counts by two or more counters, would indicate the most accurate method. It was assumed that all pups could be seen in the photographs and that ground observers saw all pups from their vantage points.

## Results

### *Pup Counts*

*Unobstructed and obstructed view*—During the 1992–1994 censuses, ground observers encountered thirty-two areas where all California sea lion pups were visible (unobstructed view) and sixteen areas where their view was partially obstructed. Ground counts and photographic counts of pups from all areas combined (*i.e.*, unobstructed and obstructed views) were significantly different (df = 1, $F$ = 20.994, $P < 0.001$). Using the Tukey HSD *post hoc* test, made after interaction effect was detected between year and method (df = 2, $F$ = 4.092, $P$ = 0.017), I found a significant difference between methods in the 1992 census ($P < 0.001$), but not in the 1993 and 1994 censuses ($P$ = 0.060 and $P$ = 0.906, respectively). Linear regression analysis of paired counts showed that (1) photographic counters counted fewer pups than ground counters when fifty or fewer pups were present, (2) photographic counters counted more when the number exceeded approximately 200, and (3) the slope of paired counts (0.905) was significantly different from 1.000 ($P < 0.001$; Fig. 2a).

*Unobstructed view*—When ground and photographic counts from thirty-two areas with unobstructed ground views were compared for the 1992–1994 censuses, no difference was detected between the two methods (df = 1, $F$ = 0.817, $P$ = 0.367) nor was there an interaction effect between year and method (df = 2, $F$ = 1.409, $P$ = 0.246). However, the slope of the regression line comparing photographic and ground counts with unobstructed views (0.959) was significantly slightly different from 1.000 ($P < 0.001$; Fig. 2b). No difference was found between counts by the two methods for rock substrates (df = 1, $F$ = 2.217, $P$ = 0.140), sand substrates (df = 1, $F$ = 0.530, $P$ = 0.468), and mixed rock-and-sand substrates (df = 1, $F < 0.001$, $P$ = 0.986). Linear regression analysis showed that the slope of paired counts made on

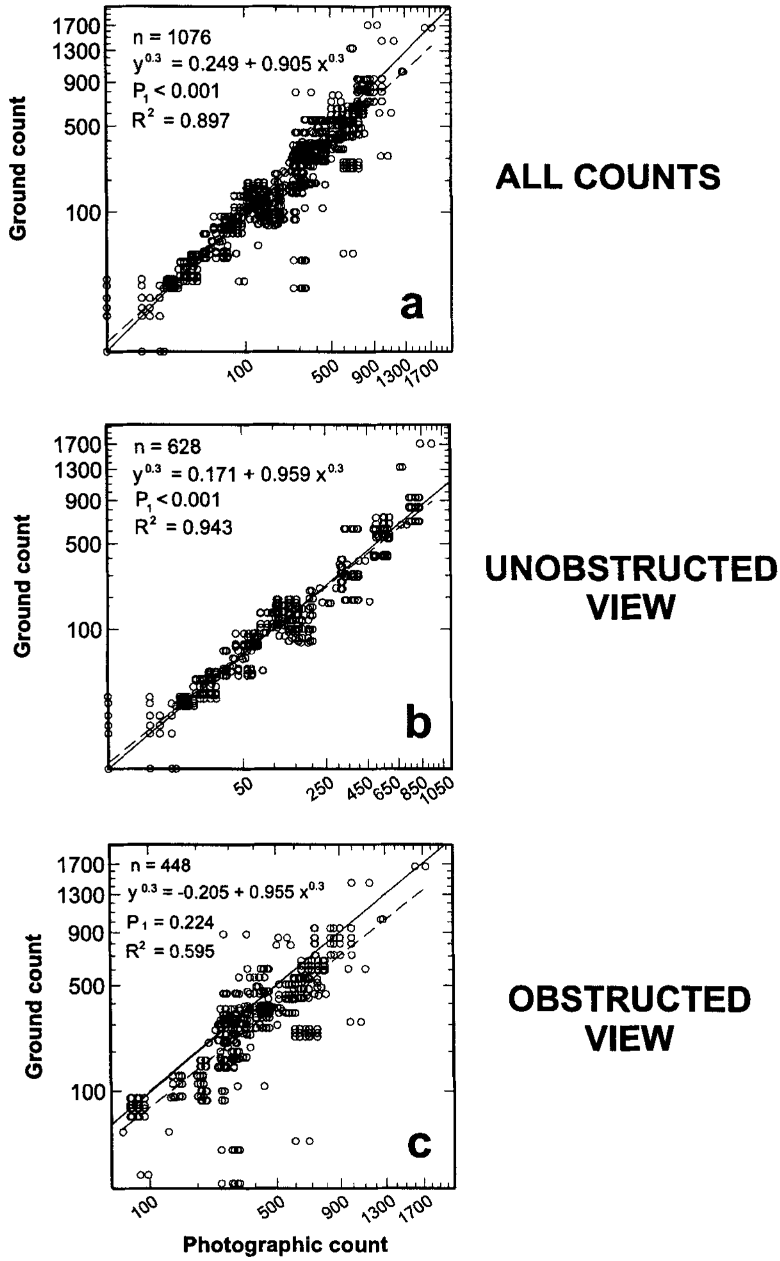


*Figure 2.* Linear regression analysis of paired ground counts and photographic counts of California sea lion (*Zalophus californianus*) pups from censuses conducted in 1992–1994 at San Nicolas Island, California: a. Counts from all areas; b. Counts from areas where ground observers had unobstructed view; and c. Counts where ground observers had obstructed view. Counts were 0.3 power transformed. Regression line (dashed line) shown in relation to 1:1 ratio (solid line).

mixed rock-and-sand substrates (0.961) was not different from 1.000 ($P$ = 0.144); but the slopes of paired counts from rock substrates and sand substrates (0.859 and 0.969, respectively) were significantly different from 1.000 ($P$ < 0.001; Fig. 3a, b, c).

*Obstructed view*—When ground observers experienced obstructed viewing conditions, at sixteen areas during the 1992–1994 censuses, their counts were significantly different from photographic counts (df = 1, $F$ = 29.226, $P$ < 0.001), but no interaction effect between year and method was found (df = 2, $F$ = 2.471, $P$ = 0.087). The regression line between photographic counts and ground counts shows that more pups were counted by photographic counters, but the slope of the regression line (0.955) was not different from 1.000 ($P$ = 0.224; Fig. 2c). Significant differences were found between counts by the two methods for rock substrates (df = 1, $F$ = 25.703, $P$ < 0.001), sand substrates (df = 1, $F$ = 5.210, $P$ = 0.028), and mixed rock-and-sand substrates (df = 1, $F$ = 13.272, $P$ = 0.001). Linear regression analysis of paired counts indicated that the slope of the regression line for counts made on sand substrates (0.942) was not different from 1.000 ($P$ = 0.675), but the slopes for rock substrates and mixed rock-and-sand substrates (0.893 and 1.125, respectively) were significantly different from 1.000 ($P$ = 0.043 and $P$ = 0.002, respectively; Fig. 4a, b, c). Ground counts were greater than photographic counts for sand substrates but not for rock or mixed rock-and-sand substrates (Fig. 4a, b, c).

### *Replicate Censuses*

Analysis of the 1993 photographic censuses of pups found no differences between replicate photographic censuses (df = 2, $F$ = 0.842, $P$ = 0.432) or between replicate counts of the same photographic census (df = 1, $F$ = 1.656, $P$ = 0.200), and there was no interaction effect between censuses and counts (df = 2, $F$ = 2.744, $P$ = 0.067). Replicate photographic censuses made during five different years (1992–1996) were not different (df = 6, $F$ = 0.254, $P$ = 0.958). In 1993, a significant difference occurred between two replicate ground censuses made one week apart (df = 1, $F$ = 4.449, $P$ = 0.037), but no difference was found between observers making simultaneous counts (df = 2, $F$ = 0.338, $P$ = 0.714). The CVs of total pup counts from photographs were about half (0.042 versus 0.078) those of ground counts during 1993, when multiple censuses and counts were made.

### *Replicate Counts*

Replicate ground and photographic counts of pups at Area 50 (Fig. 5) were significantly different from each other ($P$ < 0.05), as were counts by counters of different experience ($P$ < 0.05), but no interaction effect was found between experience level and method ($P$ > 0.5). However, replicate counts of pups by experienced counters at Areas 44 and 50 (Fig. 5, 6) were not different between the two methods ($P$ > 0.5), and, although size of the three groups of pups

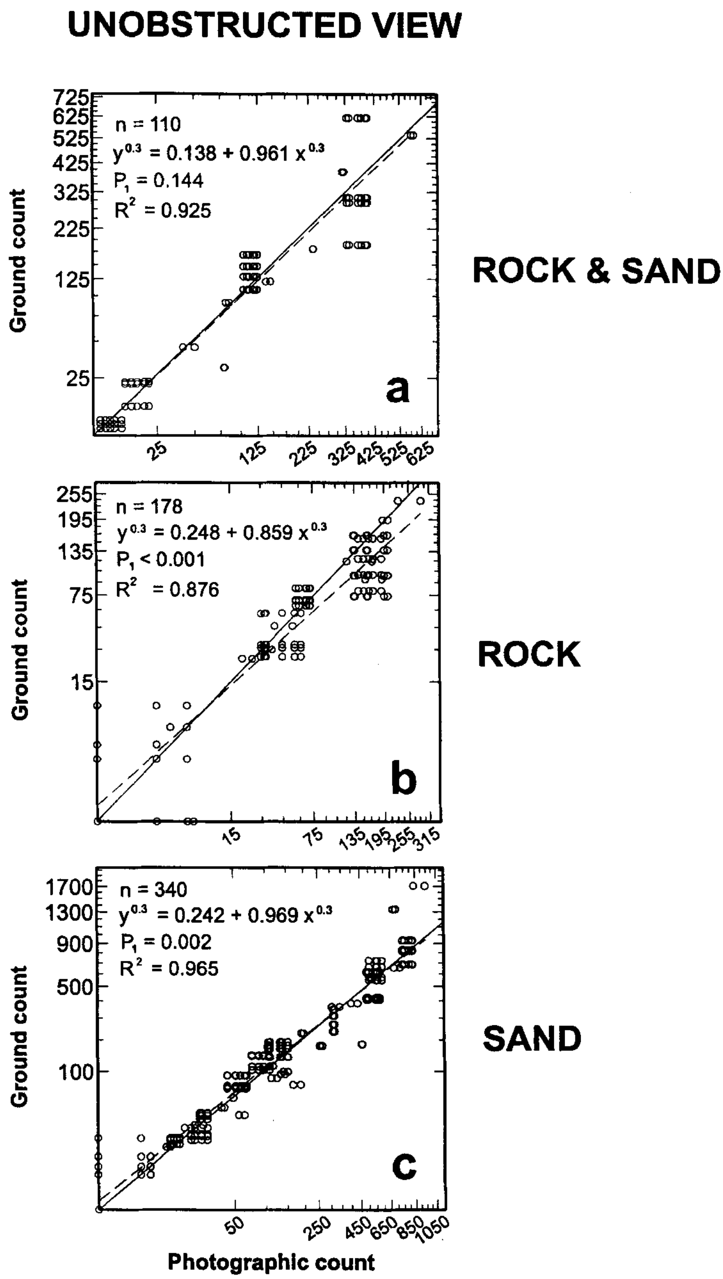


*Figure 3.* Linear regression analysis of paired ground counts and photographic counts of California sea lion (*Zalophus californianus*) pups from censuses conducted in 1992–1994 at San Nicolas Island, California for three substrate categories where ground observers had unobstructed view: a. Mixed rock-and-sand; b. Rock; and c. Sand. Counts were 0.3 power transformed. Regression line (dashed line) shown in relation to 1:1 ratio (solid line).

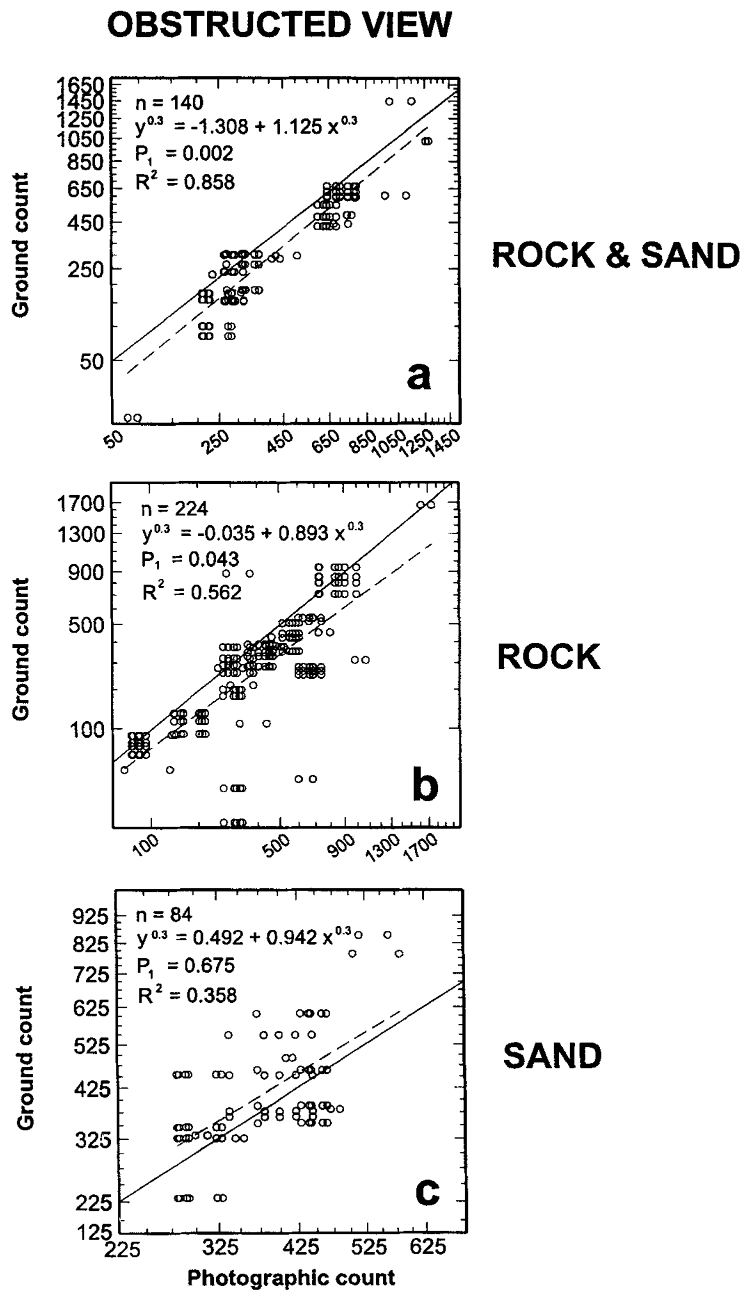


*Figure 4.* Linear regression analysis of paired ground counts and photographic counts of California sea lion (*Zalophus californianus*) pups from censuses conducted in 1992–1994 at San Nicolas Island, California for three substrate categories where ground observers had obstructed view: a. Mixed rock-and-sand; b. Rock; and c. Sand. Counts were 0.3 power transformed. Regression line (dashed line) shown in relation to 1:1 ratio (solid line).

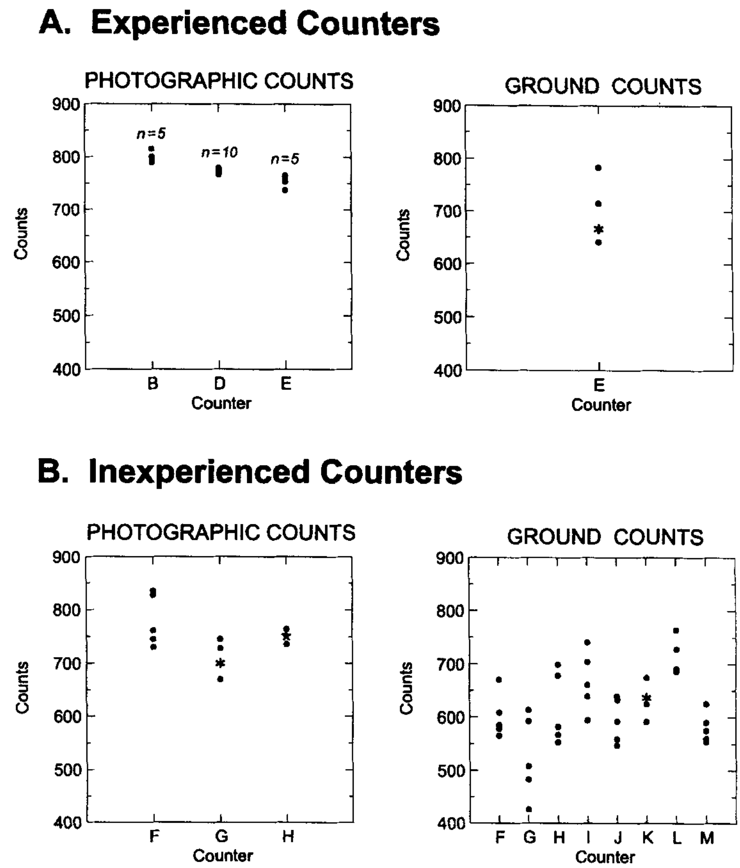


*Figure 5.* Distribution of counts made by (A) experienced and (B) inexperienced persons on ground and from 126-mm-format aerial color photographs of California sea lion (*Zalophus californianus*) pups at Area 50, San Nicolas Island, California. Filled circle (●) denotes single count, asterisk (*) two counts, and star (★) three counts. Pups photographed during ground count. Sample size for all counters = 5, except for photographic counter D ($n = 10$) and ground counter L ($n = 4$).

was significantly different ($P < 0.001$), no interaction effect was found between group size and method ($P > 0.05$).

The CVs of inexperienced and experienced counters were not different from each other ($P > 0.05$; Fig. 7A, B), and, whereas a significant difference was found between the methods ($P < 0.05$), no interaction effect was found between experience and method ($P > 0.05$). No difference was found in CVs of ground observers and photographic counters during tests in Areas 44 and 50 for group size of pups, nor was there an interaction effect between group size of pups and method ($P > 0.05$). Individual and grouped ground counters at Areas 44 and 50 had CVs higher than were achieved by experienced counters in the control set of ground counts ($P = 0.041$ and $P = 0.021$, respectively). Individual CVs of experienced counters were not different from CVs derived

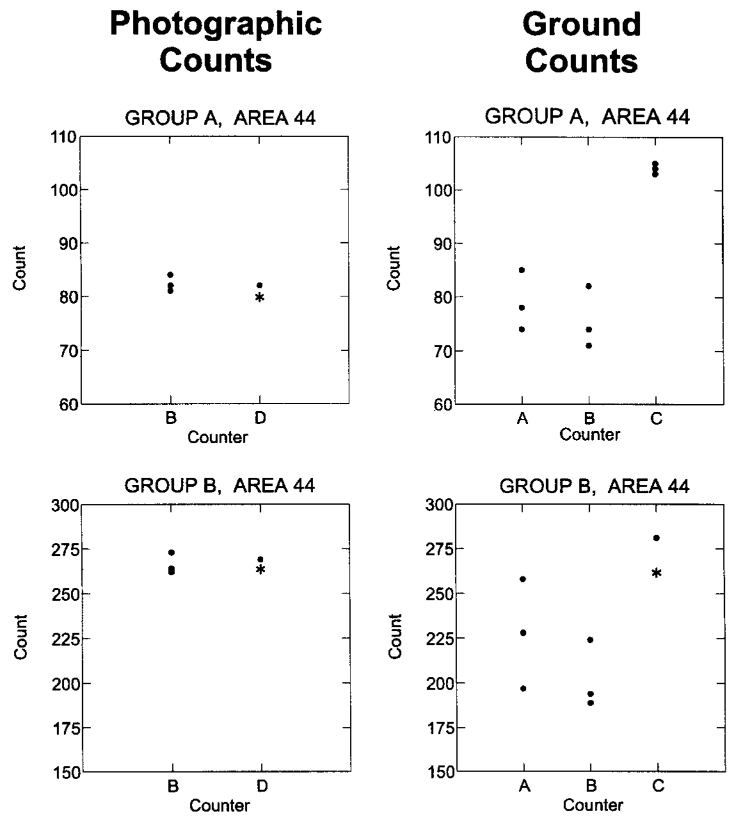


*Figure 6.* Distribution of counts made by experienced observers on ground and from 126-mm-format aerial color photographs of California sea lion (*Zalophus californianus*) pups at Area 44 (Groups A and B), San Nicolas Island, California. Filled circle (●) denotes single count, and asterisk (*) two counts. Sample size for all counters = 3.

from counts by two or more individual counters for photographic counts ($P = 0.168$) but were significantly different for control ground counts and for ground counts in Areas 44 and 50 ($P = 0.012$ and $0.040$, respectively). Lastly, inexperienced counters were more precise and accurate when they counted from photographs than when they counted on the ground (Fig. 5, 7B).

## Discussion

The vertical aerial photographs gave photographic counters a better view of pups than was achieved by ground observers during islandwide censuses. That advantage, along with higher precision of photographic counts (Fig. 7) and ability to mark pups on the photograph, made the aerial photographic censuses more accurate than the ground censuses. Although no difference was found between counts of pups on different substrate types when ground observers had unobstructed views, regression analysis of paired counts showed that

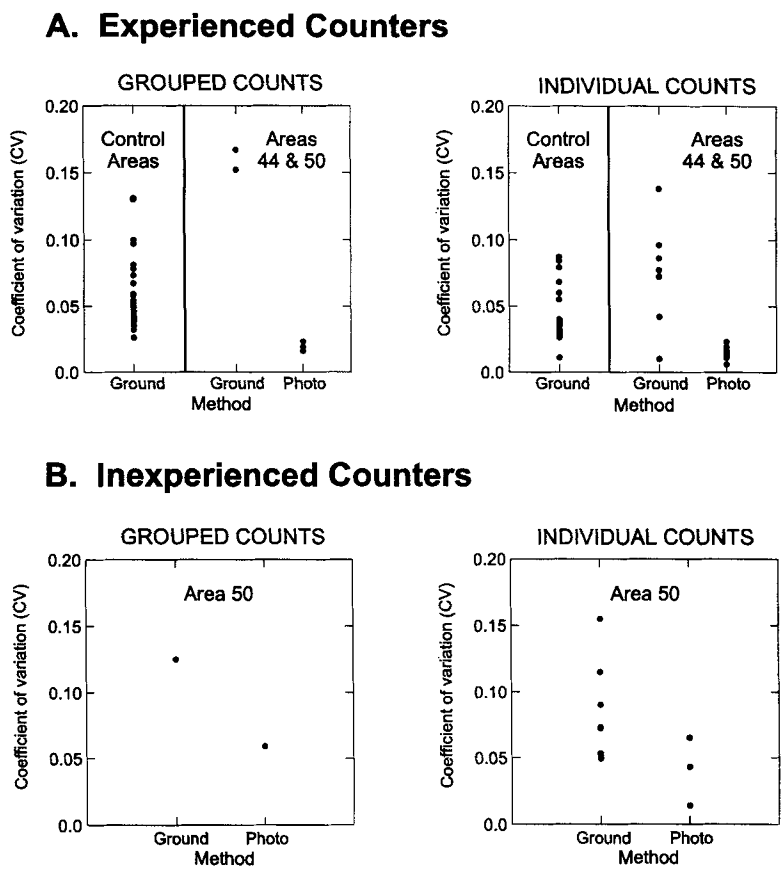


*Figure* 7. Distribution of coefficient of variation (CV) by (A) experienced and (B) inexperienced counters for individual counters and for grouped counts (*i.e.*, counts by two or more counters) from counts of California sea lion (*Zalophus californianus*) pups at Areas 44 and 50, and for control set of ground counts. Pups photographed during ground count at Areas 44 and 50 but not during control ground count.

ground observers had difficulty counting large groups of pups and did best when counting scattered individuals or small groups of pups (Fig. 2b, 3b, c).

A major difference between counts by ground observers and counts from photographs was that photographic counts were more precise than ground counts (Fig. 5, 6, 7). Counter experience and size of pup groups did not affect precision for either method. Precision and counts were more consistent between photographic counters than between ground observers. Ground counts were not as accurate—possibly because of low precision caused by movement of pups and inability to prevent double- or under-counting. The low precision and inaccuracy of ground counts may explain why replicate ground censuses conducted in 1993 were significantly different from each other. However, pup mortality, although assumed to be insignificant between censuses, could be another reason for the difference.

"Ground truth" implies that counts made by observers on the ground are accurate and precise. Although ground observers had an unobstructed view of all pups during the comparisons at Areas 44 and 50, counts were more variable than those of the photographic counters. It is possible that counts by ground observers walking among sea lions (*i.e.*, "drive counts") may produce different results than a count made from an observation point. However, these two methods were not compared in this study because the walk-through approach would be very disruptive to the animals and was not attempted for that reason. Most importantly, however, the results showed that experienced ground observers count better than inexperienced ground observers, and that both experienced and inexperienced ground observers have higher counts when they count from photographs (Fig. 5, 7).

Ground observers would need to disturb sea lions and other pinnipeds present to view and count all pups when their view is partially obstructed. While this would allow them to view all pups, movement of animals caused by their presence would result in loss of precision and accuracy. Aerial photographic censuses, which are not affected by movement of pups, miss pups in caves, under large rocks and overhanging cliffs or when obscured by dark shadows, resulting in loss of accuracy. It is apparent, then, that each method has specific advantages. Which method is used will be governed by the terrain and accessability of each rookery. The ideal situation may be to use both methods, using the strengths of each to obtain a good count.

Differences in monetary cost between effective aerial photographic censuses and ground censuses also may dictate which method is used to census California sea lion pups or other pinnipeds. Aerial photographic censuses with the camera system used here (photogrammetric companies may have comparable systems available) can cost more than ground censuses. However, transportation of ground observers and establishment of field camps at remote rookeries may make ground censuses impractical or less economical in some cases. Safety of personnel on the ground or in an aircraft, time needed to conduct the census, terrain of the rookery, and the geographical distribution of the animals would also need to be considered. Aerial photographic censuses can be a cost-effective way to census pinnipeds distributed over many kilometers or found at remote locations. Photographs can be re-examined days, weeks, months, or years afterwards to check the counts obtained or to answer new questions. A ground census produces only a notebook with numbers and notes and does not allow researchers to go back in time and recollect the data.

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*Appendix* Total counts of California sea lion (*Zalophus california*) pups at San Nicolas Island, California from 126-mm-format aerial color photographs and from the ground. Photographic counts made by the author. Repeat counts of each census (date) made in 1993. Land counts in 1992 and 1994 made by team of three observers whose counts of different sections of rookery were summed to make total count. Ground counts in 1993 made by four different observers; each counted entire rookery.

| | Photographic count | | Ground count | |
|---|---|---|---|---|
| Year | Date | *n* | Date | *n* |
| 1990 | 18 July | 10,683 | | |
| | 25 July | 11,766 | | |
| 1991 | | | 19–21 July | 11,827 |
| 1992 | 18 July | 8,869 | 16–17 July | 6,468 |
| | 23 July | 9,348 | | |
| 1993 | 11 July | 10,595 | 16–18 July | 9,262 |
| | 11 July | 10,538 | 16–18 July | 9,748 |
| | 15 July | 9,702 | 23–26 July | 8,382 |
| | 15 July | 10,409 | 23–26 July | 8,723 |
| | 17 July | 9,698 | | |
| | 17 July | 10,345 | | |
| 1994 | 14 July | 15,766 | 12–13 July | 16,503 |
| | 16 July | 16,889 | | |
| 1995 | 21 July | 17,512 | | |
| | 22 July | 16,926 | | |
| 1996 | 21 July | 19,308 | | |
| | 22 July | 20,285 | | |
| 1997 | 14 July | 20,488 | | |